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ECOLOGY AND BIOLOGICAL PRODUCTION OF LAKE NAKA-UMI AND ADJACENT REGIONS

4. DISTRIBUTION OF FISHES AND THEIR FOODS[1]

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With 6 Text-figures and 10 Tables

Along the coast of Japan Sea are many brackish lakes and lagoons, which are separated from the sea by sand-dunes or sand-bars. Lake Naka-umi is the largest one located on the border of the Shimane and Tottori Prefectures. The characteristic situation of it is that it joins to a lake, Shinji-ko, and to Miho Bay on opposite sides of it through narrow water-courses, namely River Ôhashi-gawa and the Sakai Channel respectively (Fig. 1). The hydrographic conditions and the distribution, abundance and mode of life of organisms are varied greatly among these three bodies of water and from season to season. Such situation has aroused interests of limnologists and oceanographers, and several papers have been published on hydrological conditions, plankton organisms and benthic animals (e.g., CHIBA, 1959; CHIBA and KOBAYASHI, 1951; ISHII, 1931; KAZIKAWA, 1955; KAZIKAWA et al., 1951, 1952a, 1952b, 1956, 1957; MIYADI et al., 1945, 1952, 1954; MIZUNO, 1965; SHIBUYA, 1955; SUDA et al., 1951; UÉNO, 1955).

Lake Naka-umi and adjacent regions have been one of the areas of intensive fishing with their varieties of fish, shrimp, mollusc and other economically important fishery products; however, very few investigations have been carried out on fishes and other fishery products (OTA, 1941, 1951). Recently a land reclamation project has been intended in the district, and Lake Shinji-ko and Lake Naka-umi are expected to become freshwater lakes after its accomplish-

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ment. As a result, the environmental conditions will be completely different from those in the present situation and most nektonic organisms are surmised to be impossible to migrate between Lake Naka-umi and Miho Bay. The survey on the distribution and mode of life of fish at present time, therefore, might be very important and affords interesting informations for the future.

Members of the Naka-umi Research Group directed by Denzaburo MIYADI investigated the regions from the ecological point of view for three years and a half (1958–1962). This paper is concerned with the distribution and movement of main fishes and their food habits. We have collected 282 species of fish belonging to 85 families, complete list of which was prepared by IWAI and ASANO (unpublished) for identification.

General Features of the Regions

The physical and chemical features and some characteristic aspects of food organisms of fishes in the regions concerned, which have been and will be treated in detail separately, are summarized here on Tables 1 and 2.

Table 1. Physical conditions of the research areas.

		Lake Shinji-ko	Lake Naka-umi	Miho Bay
area (km^2)		81.7	99.2	112.4
depth (m)	average	4.0	5.6	20
	deepest	5.2	7.5	35
water temperature (°C)				
surface	spring	17	17	16
	summer	30	30	27
	autumn	18	18	20
	winter	5	7	11
bottom	spring	16	17	15
	summer	29	30	25
	autumn	18	21	21
	winter	6	11	12
chlorinity (‰)				
surface	spring	0.6	9.5	18.3
	summer	1.2	7.4	15.2
	autumn	1.1	7.1	15.4
	winter	0.9	7.4	17.8
bottom	spring	0.7	15.2	19.0
	summer	1.3	16.1	18.2
	autumn	1.1	15.2	18.2
	winter	0.8	15.6	18.6
dissolved oxygen (%)				
surface	summer	>90	>90	>90
	winter	>90	>90	>90
bottom	summer	>70 (30 : deepest)	40–70 (northern) 0–10 (southern)	>90
	winter	>90	>70 (northern) 60–70 (southern)	>90

Table 2. Biotic conditions of the research areas.

	Lake Shinji-ko	Lake Naka-umi	Miho Bay
phytoplankters			
dominant species	*Merismopedia tenuissima* *Diploneis puella* *Cyclotella Meneghinianum* *Lyngbya limnetica* *Planctonema Lauterborni*	*Leptocylindrus danicus* *Chaetoceros mitra* *Coscinodiscus radiatus* *C. excentricus* *Thalassionema nitzschioides*	*Coscinodiscus wailesii* *Stephanopyxis palmeriana*
biomass (mm^3/l)			
spring	64	42	54
summer	163	74	60
autumn	90	75	17
winter	148	19	16
rooted aquatic plants and weeds			
dominant species	*Potamogeton malaianus*	*Zostera marina* *Z. nana* *Gracilaria verrucosa* *G. chorda*	*Sargassum hemiphyllum* *S. piluliferum*
zooplankters			
dominant species	*Pseudodiaptomus inopinus* *Sinocalanus tenellus* *Diaphanosoma brachyurum* *Keratella valga*	*Acartia clausi* *A. erythraea* *Oithona nana*	*Paracalanus parvus* *Evadne nordmanni*
biomass (mm^3/l)			
spring	2.5	7.8	9.0
summer	4.7	24.2	10.5
autumn	13.4	8.8	8.4
winter	32.1	10.3	11.2
phytal animals			
dominant species	*Anisogammarus subcarinatus*	*Ampithoe valida* *Anisogammarus subcarinatus* *Pontogeneia pacifica*	*Pontogeneia pacifica* *Caprella scaura*
benthic animals			
dominant species	*Corbicula japonica* (marginal) *Tendipes plumosus* *Tubifex* sp. (central)	*Musculus senhousia* *Fravocingla nipponica* *Anadara subcrenata* (northern) *Raeta pulchela* *Theora lubrica* *Prionospio pinnata* (southern)	*Dentalium octangularis* *Proclava pfefferi*
biomass ($g\text{-}wet/m^2$)			
spring	498.5 (marginal) 3.6 (central)	123.8 (northern) 53.6 (southern)	—
summer	480.1 (marginal) 2.0 (central)	21.6 (northern) 2.0 (southern)	—
autumn	190.5 (marginal) 1.7 (central)	4.9 (northern) 0.0 (southern)	—
winter	191.4 (marginal) 1.6 (central)	4.9 (northern) 0.2 (southern)	5.6

Lake Shinji-ko is weakly brackish. Chlorinity is highest in summer, but attaining only to 1.36‰, gradually decreases during colder seasons and becomes lowest in spring. Water temperature changes seasonally in large degree: 5.5–5.9°C in winter and 27.4–31.6°C in summer. The stratification of water is not serious throughout the year in view of water temperature, chlorinity and dissolved oxygen, with the exception of the deepest part of small area where chlorinity is about 3‰ and dissolved oxygen concentration is less than 30% in summer. The lake may be divided into two parts according to the distribution of benthic animals: a clam, *Corbicula japonica*, is predominant in marginal sublittoral region and chironomid larvae, *Tendipes*, and an aquatic oligochaete, *Tubifex*, are dominant in profundal region. Biomass of them are 200 to 500 g-wet weight/m^2 in the former region and 1 to 4 g-wet weight/m^2 in the latter. No marked difference is observed in both phyto- and zooplankton distribution in the lake. Chlorophyll content and production rate of phytoplankters are 1.4 to 10.6 mg/m^2 and 120 to 1,400 mg-carbon/m^2/day respectively, while biomass of zooplankters is 27 to 730 g-dry weight/m^2. Aquatic rooted plants are few even in marginal region and biomass of them is at largest only 2.85 ton (dry weight) for the whole lake.

In Lake Naka-umi, the stratification of water is distinct throughout the year with respect to the hydrological conditions. Water temperature in winter is 5.9–8.0°C in the surface layer in contrast to 10.8–12.5°C in the bottom layer, whereas 28.8–31.1°C and 23.4–27.8°C respectively in summer. Seasonal change of chlorinity is reversed between the surface and the bottom layer. In the surface layer the maximum is observed in winter (8.80–10.27‰) and the minimum is in summer (5.68–7.97‰); on the contrary, the maximum is in summer (15.10–17.26‰) and the minimum is in winter (8.86–16.19‰) in the bottom layer. Thus the stratification is more remarkable in summer. Dissolved oxygen concentration of water falls down to less than 10% at the bottom layer in summer in the southern part of the lake, which is separated by the Daikon-shima and E-shima Islands from the northern part where dissolved oxygen concentration is 40–70% near the bottom even in summer. The bottom fauna in the deeper part than 3 metres of the southern part is, therefore, very poor in summer, and no bottom animals but small bivalves, *Raeta pulchela* and *Theora lubrica*, which have short life-span, and small polychaetes, *Prionospio pinnata*, strongly resistant to low oxygen concentration, occur there. Plankton organisms are not much different between the southern and the northern part, although the vertically stratified distributions are seen in both parts. Biomass and production rate of phyto- and zooplankters are larger in summer than in winter: i.e., about three times in chlorophyll content of water, about twenty times in production rate of phytoplankters, and about two times in biomass of zooplankters. Aquatic rooted plants and phytal algae and animals are abundant in the lake, biomasses of which are 1,400 tons and 3.3 tons in dry weight respectively.

Miho Bay is fully exposed to east and north, and the hydrographic condi-

Table 3. Percentage compositions of the yields of main fishes to the total catches, calculated for each fisheries cooperative association on the Shimane Prefecture coasts of Lake Shinji-ko, Lake Naka-umi and Miho Bay. Data are based on the fishery statistics collected by the Shimane Prefectural Government Naka-umi Reclamation Office (unpublished). The upper figures indicate percentages calculated from the combined landings of all sorts of fishing, and the lower from those of set-nets only.

	carp	crucian carp	icefish	pond smelt	freshwater eel	common goby	sea bass	striped mullet	halfbeak	bay sardine	rockfishes	river flatfish	small silvery mackerel	jack mackerel	sea bream	Pacific sardine	amberjack
Hirata	15.4	66.1	0.5	11.2	1.4	1.9	2.3	1.2									
	0.5	13.1	1.7	78.2	2.6	1.4	1.3	0.8									
Shutto	12.8	78.7	0.2	6.2	0.4	0.4	0.2	1.1									
	0.3	42.6	0.9	53.6	0.1	2.4	0.3										
Shinji	5.0	35.1	11.7	15.0	4.4	1.5	26.8	0.5									
	0.6	23.5	16.0	47.8	0.2	15.4	2.5										
Kimachi	3.2	26.6	12.4	5.9	6.0	6.3	37.8	1.7									
	2.4	11.8	4.8	67.5	2.2	7.2	4.0	0.1									
Tamayu	5.3	24.4	11.5	16.5	10.1	7.2	23.5	1.4									
	1.0	7.2	0.6	54.6	3.2	14.0	19.1	0.3									
Ino	8.0	45.0	2.8	12.0	17.2	1.0	13.8	2.7									
	3.0	22.1	8.2	39.2	5.0	1.1	21.4										
Oono	4.9	51.3	1.0	18.6	12.3	0.3	11.6										
	2.7	11.5	0.6	61.8	3.1	0.6	18.6										
Aika	4.1	29.4	0.3	25.5	8.0	5.7	17.9	5.2									
	1.6	12.7	0.7	65.1	2.2	7.4	10.7	0.2									
Furue	2.0	26.9	0.4	20.0	5.1	20.4	23.8	1.1									
	0.1	3.2	0.2	42.3	1.9	22.9	29.4	0.5									
Ikuma	7.5	39.1	0.3	22.2	2.2	9.9	17.7	0.7									
	0.6	1.9		53.8	2.0	17.9	23.6	0.1									
Hokki	6.7	48.3	1.7	9.0	3.9	8.4	20.1	1.9									
	1.0	9.0	0.6	45.8	3.0	14.5	26.2										
Nogi	1.5	14.1	2.9	42.1	6.0	7.4	24.5	1.5									
	0.5	6.3	0.1	67.5	0.7	2.0	22.6	0.2									
Matsue	1.2	10.0	13.0	19.1	4.4	25.8	23.5	0.9									
	0.2	3.8	13.7	23.9	3.1	26.8	27.7	0.8									
Kawazu & Tsuda	4.1	58.7	3.6	3.5	2.9	22.8	3.2	1.1									
	0.1	1.4	21.7	18.0	3.5	31.5	18.2	5.6									
Asakumi & Chikuya 1	3.8	37.8	8.6	17.3	3.0	12.0	9.3	9.1									
	0.1	2.1	5.9	9.0	0.9	5.1	67.3	9.7									
Asakumi 2		1.0	10.3	11.2	11.7	24.2	7.0	1.1	2.8	27.5			1.2				
				2.9	5.8	45.2	6.9		2.2	35.4			0.6				
Chikuya 2			8.0	5.2	3.1	22.4	10.4	1.1	5.1	36.1		0.3	6.6	0.8			
				0.6	2.0	28.6	9.2		4.5	47.1		0.3	5.6	1.0			
Iya			1.8	7.0	2.3	28.4	4.1	11.4	3.1	32.4	0.8	0.1	8.0				
				10.7	1.0	43.9	1.7		4.1	32.7			6.0				
Ito			0.1	1.1	1.8	3.3	8.9	75.3	0.6	3.2	0.1	0.5	3.9	0.2			
				0.3	0.4	46.3	0.1		1.3	46.4		1.3	3.7				
Arashima				0.2	2.6	22.0	8.7	26.1	0.7	30.7	0.1	1.0	6.2	0.5			
				0.3	0.2	34.8	9.8		1.1	46.8		1.7	3.8	1.0			
Akae					5.9	27.4	8.0	12.0	0.8	29.3		2.2	9.9				
					0.2	34.8	9.8		1.1	40.1	0.1	3.9	8.7				
Yasugi			1.5	6.0	5.6	47.6	13.3	0.5	2.6	16.8	0.2	1.0	4.9				
				6.3	0.6	49.3	14.7		2.1	20.9	0.3	10.3	4.7				
Shimada					8.5	64.1	3.0	0.5	1.5	16.4		1.6	3.4				
					1.1	74.7	4.1		0.2	20.0							
Yatsuka					11.0	20.0	6.0	26.0	9.1	14.2	1.9	2.1	8.4	0.1			
					0.7	10.8	3.9		1.0	36.1	0.7	0.4	45.6	0.9			
Omizaki			5.3	4.9	3.2	37.9	8.7		1.2	20.3	0.3	0.1	14.2	3.7			
				5.0	3.7	43.3	8.5		1.5	20.6	0.4	0.1	12.4	4.0			
Honjo				2.9	5.1	31.1	7.2	0.4	1.7	24.5	1.5	3.9	12.3	9.1			
				2.9	4.3	46.6	5.2		1.7	16.8	1.0	2.1	10.7	8.5			
Mambara					9.5	21.5	12.6		1.9	17.7	5.2	9.0	10.5	11.9			
					9.0	32.8	10.5		2.0	12.2	4.5	7.1	9.1	12.6			
Shimoubeo					11.3	39.6	6.7	0.2	1.8	18.8	5.0	4.3	11.3	0.3			
					11.5	32.7	6.7		1.9	19.4	5.1	4.5	11.7	5.8			
Moriyama				0.1	1.2	23.4	14.7	0.5	0.9	15.8	3.0	11.9	17.7	0.3			
				0.4	1.9	5.1	15.3	0.1	1.3	37.1	5.7	3.1	21.5	3.3			
Fukuura							3.7		6.0	82.5	0.8	1.5	0.5		0.3	2.8	
							58.7				41.3						
Mihogaseki						0.5	2.6	0.2	0.5	25.8	0.2	1.5	1.1	10.6	48.9	1.1	2.1
						2.5	3.6			1.0	0.7	3.5	5.6	19.1	0.1	33.1	3.3
opener sea							1.1		0.1	0.1	1.0		5.0		10.5	0.4	34.1

tion is practically oceanic: water temperature is 11.4 to 29.0°C, chlorinity is 12.34 to 19.06‰, and dissolved oxygen concentration is more than 90% throughout the year. Chlorophyll content and production rate of phytoplankters in summer is about same and twice as those in winter respectively, while biomass of zooplankters in the former season is ten times of that in the latter season.

Distribution of Main Fishes

Informations on the distribution of fish in the regions were chiefly derived from two different kinds of fishery statistics. The annual catch records, accumulated and arranged by the Shimane Prefectural Government Naka-umi Reclamation Office for the years from 1959 to 1961, are based on a practically complete census made directly on more than 98 per cent of fishermen for each kind of fishing. However, the statistics give us informations neither about seasonal changes of yields nor about exact sites of fishing, except in the case of catch records of set-nets, and, moreover, lack the data from coasts of the Tottori Prefecture.

For supplying these weak points, fifty fishermen chosen from about 2,500 engaged in fishing in the regions, including those of the Tottori Prefecture, were requested to keep daily catch records of each species of fish on a kind of hand-sort punch cards. The maximum and minimum sizes and weights as well as site and time of fishing were therewith entered on. The cards were then collected and rendered for analysis.

Samples of fish were obtained using various fishing gears to provide another source of information and to elaborate analyses of the data of statistics. The gears employed were such as a large cone-net (mouth diameter of 1 m, about 35 meshes to an inch), a medium-size cone-net (mouth diameter of 50 cm, about 40 meshes to an inch), smaller drag-nets, a small beam trawl, a dragging coracle-net called "Genshiki-ami", a filtering set-net called "Kobukuro-ami", a large square set-net called "Masu-ami", a stab-net, hand-nets, anglings, etc.

Table 3 shows the percentage composition of the yield of fish based on the fishery statistics collected by the Shimane Prefectural Government (unpublished data) mentioned above. From these data, MORISHITA's similarity indices (1959) of the catch between fisheries cooperative associations are calculated and shown in Table 4. In Table 5, the daily catches recorded by fifty fishermen are summarized to show regional and seasonal differences of the yield of fish.

From these results, the following fifteen areas may be distinguished according to fish distribution (Table 6).

Table 4. Similarity indices of the catch between two fisheries cooperative associations, calculated from the data in Table 3. Right-upper and left-lower halves indicate those for overall catches and for set-net catches respectively.

	H	S	S	K	T	I	O	A	F	I	H	N	M	K & T	A1 & C1	A2	C2	I	I	A	A	Y	S	Y	O	H	M	S	M	F	M	O
Hirata		91	88	55	61	79	93	70	62	83	91	41	16	92	83	08	04	05	02	03	03	05	03	00	05	07	03	03	06	00	02	00
Shutto	86		67	50	55	84	81	61	54	75	84	30	14	91	74	04	04	02	03	01	01	01	01	00	11	01	00	01	00	00	00	00
Shinji	87	92		93	99	46	89	81	87	92	93	75	29	77	77	29	10	13	25	12	13	21	07	07	02	01	02	01	02	00	00	00
Kimachi	81	79	92		93	80	71	78	84	80	82	66	32	60	73	34	03	19	35	23	24	37	17	12	30	68	35	24	36	03	04	01
Tamayu	89	79	90	94		87	80	30	90	90	85	80	32	63	87	45	33	24	34	23	25	37	20	17	34	27	35	28	33	02	02	01
Ino	77	84	87	95	89		96	38	81	95	99	62	23	88	96	25	14	49	30	11	01	15	08	09	12	11	19	14	12	01	01	01
Oono	61	85	88	95	97	90		87	78	97	94	64	22	88	90	19	10	08	07	08	08	11	04	04	09	08	11	08	12	01	01	00
Aika	98	88	80	99	98	82	99		91	98	92	87	28	58	92	34	24	26	46	25	23	29	15	14	50	22	25	27	23	15	02	00
Furue	73	99	80	81	96	84	87	86		93	86	70	36	73	87	49	40	39	30	32	39	58	43	08	52	42	45	46	47	02	08	01
Ikuma	85	71	85	90	99	84	94	95	99		94	81	31	83	94	32	24	23	16	02	19	32	20	01	28	23	24	22	25	01	02	00
Hokki	70	74	86	77	98	91	93	92	99	98		59	28	91	91	25	17	17	24	16	18	19	17	09	22	19	22	20	22	02	02	01
Nogi	85	80	84	96	96	86	99	99	99	95	91		36	38	67	43	30	27	26	18	20	35	17	10	31	24	26	21	26	02	02	01
Matsue	47	44	68	57	76	25	63	62	93	82	86	83		14	20	25	21	20	07	16	07	32	28	18	27	22	19	24	14	03	35	00
Kawazu & Tsuda	38	33	16	47	63	57	47	49	79	66	60	45	99		87	25	21	23	04	10	23	34	34	09	96	07	21	30	21	00	06	00
Asakumi & Chikuya 1	16	13	20	21	46	53	41	30	24	52	59	44	68	51		37	26	30	64	27	26	34	04	17	37	25	22	77	23	01	01	00
Asakumi 2	07	05	31	08	47	13	11	18	50	37	37	33	65	72	20		96	99	04	08	86	81	68	39	86	86	77	84	69	53	30	00
Chikuya 2	02	03	16	07	18	06	06	15	30	22	22	09	48	42	20	90		46	24	37	45	57	09	23	59	51	47	53	40	08	06	01
Iya	19	01	38	26	36	18	19	27	17	40	38	21	55	60	11	89	90		65	91	99	82	73	31	92	92	77	85	79	60	33	00
Ito	00	01	02	01	17	02	01	08	29	21	19	25	38	45	26	83	94	96		77	97	25	15	15	29	29	33	23	38	09	67	01
Arashima	02	03	17	08	20	09	06	06	33	24	24	24	27	45	21	97	99	93	91		68	70	60	49	76	78	68	71	68	57	20	01
Akae	06	02	13	06	16	06	04	08	28	36	20	25	36	39	15	91	74	78	81	81		83	73	38	91	92	82	90	83	56	32	00
Yasugi	11	11	36	21	39	18	03	24	50	45	45	21	70	73	34	10	51	94	88	86	64		94	30	98	90	77	95	78	30	17	00
Shimada	03	03	25	10	23	18	03	11	40	29	26	44	52	60	12	32	68	86	85	75	62	91		21	87	78	63	92	96	05	12	00
Yatsuka	04	07	05	02	06	03	04	03	11	08	08	08	14	15	08	06	34	50	76	65	50	47	18		38	40	43	22	41	12	08	00
Omizaki	10	10	11	10	34	17	15	13	43	39	38	16	24	68	88	81	83	80	87	85	63	97	74	44		90	86	96	76	38	23	01
Honjo	07	07	35	15	29	11	09	17	46	35	33	33	60	67	17	31	18	55	85	55	46	95	84	39	93		92	94	88	46	31	02
Mambara	02	03	18	09	03	14	08	13	45	26	32	30	61	67	18	31	69	78	71	73	39	86	68	49	48	93		86	89	38	09	01
Shimoubeo	03	03	03	12	01	08	08	15	22	39	42	35	09	29	09	32	39	49	70	12	73	81	88	88	63	85	88		84	28	20	01
Moriyama	01	01	05	06	01	01	09	08	22	16	19	11	26	21	31	75	57	60	60	76	27	52	28	86	33	50	21	97		33	22	01
Fukuura	01	00	00	00	00	00	00	01	04	03	04	03	44	22	08	11	55	02	02	13	09	02	04	06	09	09	23	24	31		43	00
Mihogaseki	00	00	00	00	00	00	00	00	07	05	06	03	09	08	08	14	14	12	06	10	06	10	06	14	07	17	10	39	17	07		22
opener sea	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Table 5. The yields of main fishes captured in respective parts of the regions during summer (upper row) and winter (lower row) by 50 selected fishermen. Data are based on the daily catch records kept by them. Weight in 10 kg.

	Lake Shinji-ko		River Ôhashi-gawa		Lake Naka-umi			Sakai Channel		Miho Bay		
	west	east	west	east	west	east & south	north	west	east	west	north	central
carp	23	15	3	1								
	12	8	1									
crucian carp	350	142	11	2								
	68	37	7									
icefish												
	98	28	624	30	30							
pond smelt	281	92	12	27	3	2						
	1813	1012	587	50	21		5					
freshwater eel	57	86	89	29	61	76	221	11	5			
	10	3	17	27		4	13	11	2			
common goby	13	9	51	3	230	1147	26	5	25		5	
	18	72	456	29	186	814	1035	94	10		8	
sea bass	167	96	130		194	148	214	103	16	15	55	
	39	56	239		19	24	23	25	13	2	101	
striped mullet	7	9	10	8	685	1315	28	2	609	6		
	1	6	3	7	10	9	3	2	1	3		
halfbeak		8	9	2	68	10	28	14		4	1	
					19	15	8	19	40	12	1	
bay sardine		43	35	12	864	186	96	114	1	39	9	
		8	17	1	41	89	29	108	74	60	7	
small silvery mackerel		32	363	42	129	264	215	64	19	170	120	
		2	11	8	5	12	7	9		75	76	
black porgy			1	1	1	1	6	2	3		27	
								1	1		7	
flathead			1	2	1	4	6	2		2	9	
											3	
needlefish				2	10	11	2	1		3		
					10	1						
grunnel				1	3	1	3	5	1			
					2	3					1	
rockfishes					2	5	14	20	15		52	
						5	5	9	2		15	
river flatfish					13	147	1	11	19	4	21	1
					1		15	2		12	42	5
northern anchovy					190	20	16			190	62	
					13	62				13	13	
Asian croaker					1		7	3	21	95	65	67
										45	90	
jack mackerel					10	1	172	33		554	90	2
										94	22	7
siganer							4	85	1			
								9				
sea bream							4	14	5	20	53	25
										6	17	5
Pacific sardine							4			166	40	
							2			80	7	

Table 6. Occurrence of main fishes in 15 distinguished areas of the regions, as shown in the text. Symbols indicate seasonal abundance as follows : Y, occurring throughout the year ; S, occurring mainly in summer ; W, occurring mainly in winter.

	Lake Shinji-ko					Lake Naka-umi					Miho bay				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
shad				S	S	S	S	S	S	S	S	S	S	S	S
round herring									S	S		S	S	S	Y
Pacific sardine										S		S	Y	Y	Y
bay sardine			S	S	S	Y	Y	Y	Y	Y	Y	Y	Y	W	W
northern anchovy						S	S	S	S	S		Y	Y	Y	Y
pond smelt	Y	Y	Y	Y	W	W				W	W	W			
icefish	Y	Y	Y	Y	W	W					W				
lizardfish										Y		Y	Y	Y	Y
carp	Y	Y	Y	Y	S			Y	Y						
crucian carp	Y	Y	Y	Y	Y			Y	Y						
herbivorous chub	Y	Y	Y	Y	S										
freshwater eel	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y			
conger eel									S	Y		Y	Y	Y	Y
morey										S		S	S	S	Y
needlefish					S	S	S	S	S	S		S	S	S	Y
halfbeak			S	S	S	Y	Y	Y	Y	Y	Y	Y	Y	W	W
flying fish										S		S	S	S	Y
silverside												Y	Y	Y	Y
striped mullet	S	S	S	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
barracuda										S		S	S	S	Y
cutlassfish										S		S	S	S	Y
jack mackerel							S			Y	S	Y	Y	Y	Y
amberjack															Y
small silvery mackerel					S	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
sea bass	S	S	S	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Asian croaker							S			S		S	Y	Y	Y
nibbler							S			S		S	Y	Y	Y
black porgy				S	S	S	S			S		S	Y	Y	Y
sea bream							S			S		S	S	S	Y
Asian pigfish				S	S	S	S			Y		Y	Y	Y	Y
dragonet							S			Y		Y	Y	Y	Y
sand lance													Y	Y	Y
grunnel					S	S	Y	S	S	Y		Y	Y	Y	Y
common goby	S	S	S	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
surfperch					S	S	S			S		S	S	S	Y
siganer							S			Y		Y	Y	Y	Y
net-like filefish										Y		Y	Y	Y	Y
puffer										Y		Y	Y	Y	Y
black rockfish										Y	S	Y	Y	Y	Y
yellow rockfish							Y			Y	S	Y	Y	Y	Y
common greeling										S		S	S	S	Y
green greeling										S		S	S	S	Y
flathead				S	S	S				Y		Y	Y	Y	Y
searobin										S		S	S	S	Y
left-eyed flounder										S		S	Y	Y	Y
turbot										S		S	S	S	Y
river flatfish										Y	S	Y	Y	Y	Y
sole													Y	Y	Y

1) Western end of Lake Shinji-ko (area of the Hirata and Shuttô Fisheries Cooperative Associations). Crucian carp (*Carassius gibelio*) is predominant, and carp (*Cyprinus carpio*), herbivorous chub (*Ischikauia steenackeri*) and fresh-water

eel (*Anguilla japonica*) are abundant throughout the year. Pond smelt (*Hypomessus olidus*) is also abundant, but icefish (*Salangichthys microdon*) is few. Sea bass (*Lateolabrax japonicus*), striped mullet (*Mugil cephalus*) and young stages of common goby (*Acanthogobius flavimanus*) enter here mainly in summer.

2) Western part of Lake Shinji-ko (area of the Ino, Oono, Aika, Shinji and Kimachi Fisheries Cooperative Associations). Crucian carp and pond smelt are dominant, and icefish is abundant especially along the south shores. Sea bass is fairly abundant, and common goby and striped mullet occur mainly in summer.

3) Eastern part of Lake Shinji-ko (area ot the Furue, Ikuma, Hokki, Tamayu and Nogi Fisheries Cooperative Association). Pond smelt and crucian carp are dominant, and icefish is abundant. Sea bass and common goby are fairly abundant in summer. Bay sardine (*Harengula zunasi*) and halfbeak (*Hemiramphus kurumeus*) enter here also in summer.

4) Eastern end of Lake Shinji-ko and western part of River Ôhashi-gawa (area of the Matsue Fisheries Cooperative Association). Dominant species are crucian carp, pond smelt, icefish, sea bass and common goby. Carp, freshwater eel and striped mullet are also common throughout the year. Shad (*Konosirus punctatus*), halfbeak, flathead (*Platycephalus indicus*), Asian pigfish (*Therapon oxyrhynchus*) and black porgy (*Mylio macrocephalus*) occur in summer.

5) Eastern part of River Ôhashi-gawa (area of the River Fisheries Cooperative Associations of Kawazu, Tsuda, Asakumi and Chikuya). Carp and crucian carp are rather uncommon. Sea bass and common goby are dominant, and freshwater eel and striped mullet are common throughout the year. Pond smelt and icefish are abundant mainly in colder seasons; while bay sardine, shad, needlefish (*Ablennes anastomella*), halfbeak and small silvey mackerel (*Leiognathus nuchalis*) are common in summer, as well as black porgy, Asian pigfish, grunnel (*Enedrias neblosus*) and surfperch (*Ditrema temmincki*) in reduced degree.

6) Western end of Lake Naka-umi (area of the Sea Fisheries Cooperative Associations of Asakumi and Chikuya). Bay sardine and common goby are predominant. Carp and crucian carp are absent except immediately after heavy rainfall. Sea bass, striped mullet, freshwater eel, small silvery mackerel and halfbeak are abundant throughout the year. Pond smelt and icefish are also abundant mainly in winter. Northern anchovy (*Engraulis japonica*), needlefish, black porgy, Asian pigfish, surfperch, grunnel, etc. occur in summer.

7) South-western part of Lake Naka-umi (area of the Iya, Itô and Arashima Fisheries Cooperative Associations). Bay sardine and common goby are predominant. Pond smelt and icefish are not so abundant as in the preceeding area even in winter. Sea bass, striped mullet, freshwater eel, small silvery mackerel, halfbeak, yellow rockfish (*Sebastes oblongus*) and grunnel are abundant throughout the year. Northern anchovy, needlefish, black porgy, Asian pigfish,

surfperch, jack mackerel (*Trachurus japonicus*), Asian croaker (*Sillago sihama*), nibbler (*Girella punctata*), young stages of sea bream (*Chrysopharys major*), dragonet (*Callionymus richardsoni*) and siganer (*Siganus fuscescens*) are found in summer.

8) South-eastern part of Lake Naka-umi (area of the Akae, Yasugi and Shimada Fisheries Cooperative Associations). Bay sardine and common goby are predominant. Fish fauna and its seasonal change are generally similar to that in the second-preceeding area, but crucian carp and carp occur here and icefish, black porgy, Asian pigfish, surfperch and flathead are absent throughout the year.

9) Eastern part of Lake Naka-umi (area of the Fisheries Cooperative Associations of the Tottori Prefecture side). Fish fauna includes nearly same species as in the preceeding area, but pond smelt is absent throughout the year. Round herring (*Etrumeus micropus*) and conger eel (*Conger myrister*) are present in summer.

10) Central part of Lake Naka-umi (area of the Yatsuka Fisheries Cooperative Association). Bay sardine, common goby, small silvery mackerel and halfbeak are dominant. Freshwater eel, sea bass, yellow rockfish, black rockfish (*Sebastes inermis*), river flatfish (*Kareius bicoloratus*) and jack mackerel are abundant. Lizzardfish (*Saurida uncosquamis*), conger eel, needlefish, Asian pigfish, dragonet, grunnel, siganer, net-like filefish (*Rundarius erocodes*), puffer (*Fugu niphobles*) and flathead also occur throughout the year. Round herring, Pacific sardine (*Sardinopsis melanosticta*), morey (*Muraenesix cinereus*), flying fish (*Prognichthys agoo*), barracuda (*Sphyraena pinguis*), cutlassfish (*Trichiurus japonicus*), nibbler, black porgy, sea bream, surfperch, common greeling (*Hexagrammos otaki*), green greeling (*Agrammos agrammos*) and searobin (*Chelidonichthys kumu*) are found mainly in summer, while pond smelt is present in winter.

11) Western part of Lake Naka-umi (area of the Ômizaki Fisheries Cooperative Association). Bay sardine and common goby are predominant, and sea bass, striped mullet, freshwater eel, small silvery meckerel and halfbeak are abundant throughout the year. Pond smelt and icefish are also abundant only in colder seasons. Yellow and black rockfishes, river flatfish and jack mackerel are taken in summer.

12) Northern part of Lake Naka-umi (area of the Honjô, Mambara and Shimo-ubeo Fisheries Cooperative Associations). Bay sardine and common goby are predominant, and small silvery mackerel is dominant. Sea bass, striped mullet, freshwater eel, halfbeak, northern anchovy, silverside (*Allanetta bleekeri*), yellow and black rockfishes, river flatfish, jack mackerel, etc. are abundant throughout the year. Fish fauna resembles that of the second-preceeding area.

13) Western part of the Sakai Channel (area of the Moriyama Fisheries

Cooperative Association). Bay sardine, sea bass, river flatfish and small silvery mackerel are dominant. The area has a similar fish fauna to the preceeding area, but slightly differing in that: freshwater eel is not so abundant; jack mackerel, Asian croaker, conger eel, sea bream, flathead and Pacific sardine are abundant. Sand lance (*Ammodytes personatus*) and sole (*Heteromyctes japonicus*) are available.

14) Eastern part of the Sakai Channel (area of the Fukuura Fisheries Cooperative Association). Sea bass, sea bream and black rockfish are dominant in summer, while bay sardine and halfbeak are predominant in winter. Abundant fishes are nearly same as in the preceeding area.

15) Miho Bay (area of the Fisheries Cooperative Associtions of Mihogaseki and of the Tottori Prefecture coasts). Main fishes are as follows: round herring, Pacific sardine, northern anchovy, flying fish, jack mackerel, amberjack (*Seriola quinqueradiata*), sea bream and sand lance.

Seasonal Migration of Main Fishes

Patterns of seasonal migration of fishes in the regions may be deduced to some extent even from Table 5 only, but for detailed discussion the following results of the survey should better be employed here.

The data from the fifty fishermen's daily catch records are rearranged to show monthly catches of fish in the three regions in Table 7. The spawning sites and seasons of main fishes, confirmed by investigations on their egg and fry distributions, their group maturities, and so on by co-workers during the survey, are referred to and summarized here in Table 8. Moreover, the results of collection with several kinds of set-nets, namely Masu-ami, Genshiki-ami and Kobukuro-ami operated in River Ôhashi-gawa, Lake Naka-umi and the Sakai Channel, give some effective informations on the migration of fish, which are also summarized in Table 9.

From the examination of these data the types of movement of fish can be divided into the following seven categories.

The first type includes a group of fishes living only in Lake Shinji-ko (or seldom along the south-eastern shore of Lake Naka-umi) throughout their life cycles. Some of purely freshwater fishes such as carp, crucian carp, herbivorous chub, etc. are the examples. They lay their eggs down on submerged plants along the shore or on and in pebble-sand bottom of rivers flowing into the lake.

The second is represented by weakly brackish fishes, in which pond smelt and icefish are included. Almost all of pond smelt spawn in River Hii-kawa, emptying itself into Lake Shinji-ko at its west end, from January to March. Young fish spread out over the whole area of the lake till June, and a considerable fraction of them migrate down to Lake Naka-umi or partly even as

Table 7. Monthly catches (kg) of main fishes in Lake Shinji-ko (S), Lake Naka-umi (N) and Miho Bay (M) by 50 fishermen around the regions.

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
pond smelt	S	10090	1178	224	26	837	1741	516	35	731	2016	4654	13066
	N	14	89	38		31	19					61	59
	M												57
icefish	S	1285	613	417	186	71							4931
	N	10	141	147									
	M												
sea bass	S	4				6	14	31	950	2199	1698	3572	384
	N	16			55	271	721	508	1366	1197	1401	183	19
	M	359		82	469	488	183	284	314	180	438	162	246
striped mullet	S	14		31	62	133	76	199	84	178	125	108	10
	N	13	1	7	27	1777	3414	5507	7252	5826	3119	615	1
	M	18		10	29	1176	358	4159	400	325	34	29	13
freshwater eel	S		1	114	218	160	448	544	567	422	458	56	1
	N	3			5	278	345	374	462	404	159	305	4
	M			3		46	7	18	12	23	71	120	17
bay sardine	S	4			46	42		1	104	390	251	201	
	N	1		4	1156	2519	1661	3338	6852	1994	1637	267	14
	M	160	40	687	242	277	105	386	348	305	202	203	30
halfbeak	S				1		1		2				1
	N			25	604	351	50	12	76	320	142	11	
	M	124	63	12	38			1		22	9	14	21
small silvery mackerel	S				5	21				583	22344	127	
	N				19	2403	850	152	488	1030	1181	209	17
	M	12		64	564	883	296	901	917	507	252	835	182
common goby	S	1264	46		2	3	62	7	38	129	526	2787	1652
	N	927	36	55	95	481	1282	3665	6873	2648	3320	5284	6673
	M	28		28	19	60	37	39	43	50	125	163	887
black porgy	S								3				
	N				1	8	24	15	13	2	11	2	1
	M	9	9	27	10	193		10	41	4	26	10	31
black rockfish	S												
	N	7	1	4	33	32	40	58	47	22	22	21	31
	M	58	19	43	67	214	85	274	220	15	53	40	40
river flatfish	S												
	N	17	1	21	13	55	210	1351	180	51	59	39	25
	M	217	135	71	68	323	85	937	577	173	386	144	56
Pacific sardine	S												
	N			1	17	20		3	18				
	M			1	800		1485	176					
northern anchovy	S												
	N			1	17	133			1	1		4	
	M			201	338	758	1374	516	5	1	2	6	1
jack mackerel	S												
	N	1				59	325	630	798	48	1	3	1
	M	5			47	749	2507	1960	449	729	488	604	523

Table 8. Spawning seasons and sites of main fishes occurring in the regions. Data are rearranged and summarized from unpublished results by IWAI, ASANO, FUSE, HARADA, TAKAMATSU and KAWANABE, and from the papers already published.

	spawning season	spawning sites	observations
PURELY FRESHWATER SPAWNERS			
carp	IV–VI	aquatic plant zone around Lake Shinji-ko and marginal rivers	the spawning behaviour and eggs laid down on aquatic plants
crucian carp	IV–VI	same as carp	same as carp
pond smelt	I–III	lower part of River Hii-kawa; few of them also in River Iinashi-gawa and River Hakuta-gawa emptying into Lake Naka-umi	spawning behaviour and eggs laid down on among sand grains
WEAK BRACKISH SPAWNER			
icefish	II–IV	south-western shore of Lake Shinji-ko, partly in River Iu-gawa	collection of just hatched larvae; degree of maturation
BRACKISH SPAWNERS			
shad	III–VI	whole area of Lake Naka-umi	KUWATANI, et al. (1958)
bay sardine	V–IX	whole area of Lake Naka-umi, Sakai Channel and western part of Miho Bay	collection of eggs and just hatched larvae; degree of maturation
halfbeak	IV–VI	aquatic rooted plants and weeds in the northern and eastern part of Lake Naka-umi	collection of eggs with plants and weeds; degree of maturation
common goby	XII–V	whole muddy bottom area of Lake Naka-umi	collection of just hatched larvae; degree of maturation
river flatfish	XI–II	the northern part of Lake Naka-umi, Sakai Channel and the western part of Miho Bay	degree of maturation
small silvery mackerel	VI–IX	the northern and western part of Lake Naka-umi	collection of eggs and just hatched larvae; degree of maturation
INSHORE SPAWNERS			
black rockfish	X–II	the northern part of Lake Naka-umi and Miho Bay	HARADA (1962)
northern anchovy	IV–XI	Miho bay and outer part, partly also in the north-eastern part of Lake Naka-umi	collection of eggs and just hatched larvae; degree of maturation
sea bass	XI–II	probably in the mouth part of Miho bay	degree of maturation; HATANAKA and SEKINO (1962)
sea bream	IV–V	Miho Bay and outer part	KAZIYAMA (1936)
OFFSHORE SPAWNERS			
jack mackerel	III–VII	offshore water; mainly in Eastern China Sea	KAMIYA (1916), UCHIDA (1958)
striped mullet	XI–XII	East China Sea	IMAI (1958)
freshwater eel		probably eastern offshore of Ryukyu Islands and Formosa	MATSUI (1957)

Table 9. Seasonal changes of total catches of each species of main fishes, captured by several kinds of set-nets in River Ôhashi-gawa, Lake Naka-umi and the Sakai Channel.

area (fishing gear) / season / fish species	River Ohashi-gawa (Kobukuro-ami)				Lake Naka-umi (Masu-ami)		Sakai Channel (Masu-ami)				Sakai Channel (Genshiki-ami)				Sakai Channel (Kobukuro-ami)			
	Sp.	Sm.	At.	Wn.	Sm.	Wn.	Sp.	Sm.	At.	Wn.	Sp.	Sm.	At.	Wn.	Sp.	Sm.	At.	Wn.
icefish	194	4	1001	1383														
pond smelt	55	8	33	55	10	20												
common goby	13	74	48	405	363	1163	76	2	46	258	196	1017	573	910	25	49	9	119
sea bass		50	22		84			82	58	9					6	9	2	
striped mullet	2	12	10															
halfbeak	6	45	151		5		4		10	2					4	9	3	76
bay sarine	17	201	275		2698	1113	140	782	212	22				9	107	200	27	72
small silvery mackerel		1	48		49	85	382	380	388	785	2	178	1146		7	40	23	42
silverside					14	12									23	36	177	1
river flatfish					38	1	2	6			5		6		51	2		
black rockfish					22	3	1310	14	4	30					1172	26		7
northern anchovy							16	67	16						168	391	77	5
jack mackerel					938		21	128								3		
Pacific sardine					12											44		

far as the Sakai Channel or the western part of Miho Bay. Between December and February, however, many of them seem to return to Lake Shinji-ko, gathering especially to the west end of it.

Icefish lay their eggs down on sandy bottom mainly in the south-western part of Lake Shinji-ko from February to April. Fry distribute over the whole area of the lake in May or June, as well as in the south-western part of Lake Naka-umi. Between January and April, however, fish migrate back to the spawning grounds.

The third type includes bay sardine, small silvery mackerel, common goby, halfbeak, river flatfish, needlefish, etc. They spend their entire life cycles mainly in Lake Naka-umi but sometimes enter either or both of Lake Shinji-ko and Miho Bay.

Bay sardines spawn anywhere in Lake Naka-umi, especially in northern part of it, from May to September. From August, a part of relatively well-grown young (more than 3 cm in body length) enter into Lake Shinji-ko and live there, but most fish remain in Lake Naka-umi. When winter comes, fish run down from Lake Shinji-ko to Lake Naka-umi, and to the northern part of Miho Bay. Between March and May, they come back to Lake Naka-umi.

The spawning place of small silvery mackerel may be north-western part of Lake Naka-umi. Planktonic eggs distribute also to the southern part, thus hatching out occurring in the whole area of the lake. Growing up to 5–6 cm in body length by the next spring, they spread also to Lake Shinji-ko and Miho Bay.

Halfbeaks lay eggs down on submerged plants and weeds along the shore of Lake Naka-umi, especially northern and eastern part of it, from April to June. General trends in distribution and migration are similar to that of bay sardine.

Common gobies lay eggs down on muddy bottom of Lake Naka-umi from December to May. Growing up to 2 cm in body length, a change in their mode of life from planktonic to benthic occurs and their distribution is expanded even to the west of Lake Shinji-ko.

River flatfish, slightly differing from preceeding fishes, spawn in the northern part of Lake Naka-umi and the Sakai Channel as well as in the western part of Miho Bay during winter. Seasonal migration between Lake Naka-umi and Miho Bay seems not necessarily to occur.

Freshwater eel, a catadromous fish, belongs to the fourth type. They spawn in middle layers of western subtropical part of the Pacific Ocean, and leptocephalee flow north-eastward to Japanese coasts (MATSUI, 1957). Larval fish ascend the Sakai Channel and then settle down in Lake Shinji-ko, Lake Naka-umi and marginal rivers. Adult fish, more than four years old, descend to Miho Bay, that are then supposed to go back to the spawned place, but NISHIMURA (1961) doubted whether they can really reach back there.

Striped mullet and sea bass compose the fifth group. Main spawning place of mullet is probably southern part of the Eastern China Sea but a few spawn also in offshore waters of southern Japan (IMAI, 1958). Larval fish of 2.5 to 3.5 cm in body length enter into Lake Naka-umi in March, stay there till October, and move back mostly to Miho Bay to live during winter. Fish being between two and four years old migrate between Lake Naka-umi (also Lake Shinji-ko in part) and Miho Bay from season to season, but a few fish remain in the former area even in winter. Spawners which are consisted of individuals of more than four years old emigrate from the regions southward to spawning place.

Sea bass may spawn at the mouth of Miho Bay from late autumn to late winter (HATANAKA and SEKINO, 1962), larval fish enter Lake Naka-umi in early spring and inhabit *Zostera* or *Sargassum* belt till October, and then most fish migrate off to Miho Bay for over-wintering.

In the sixth group are northern anchovy, jack mackerel, Asian croaker, barracuda, flying fish, common flounder, etc. They live in Miho Bay and/or open sea throughout their life cycles, but some of them enter Lake Naka-umi. For example, northern anchovies spawn in Miho Bay and the Oki Strait from March to December, mainly from April to September. Their eggs, fry and juveniles drift afloat into Lake Naka-umi mainly in summer. Jack mackerel may spawn in open sea in spring and summer, larval fish of about 12 to 15 cm in length enter Miho Bay, and stay there until they attain to the adult stage. Some of two or three years old, however, may enter even into the northern part of Lake Naka-umi.

Other fishes, such as Pacific sardine, amberjack and grouper, living only in Miho Bay and offshore waters throughout their whole life cycles make up the last category.

Now, the problem is what kind of factors determines such distributions and migrations of fishes. As was mentioned above in the preceeding section, the fifteen areas are distinguished from the occurrence of fish, and these should first be related to the physical environment which divides the regions into three distinct areas: 1) Lake Shinji-ko, 2) River Ôhashi-gawa and Lake Naka-umi, and 3) the Sakai Channel and Miho Bay.

Chlorinity difference between these three bodies of water may have controlling influences on restricted distributions of some fishes. Freshwater fishes such as carp, crucian carp and herbivorous chub are strictly restricted to Lake Shinji-ko and the south-eastern shallow part of Lake Naka-umi, where chlorinity is lower than 1.5‰ in the surface and middle layers and is lower than 5‰ even in the deepest bottom layer. On the contrary, flathead, Asian pigfish, black porgy, needlefish, small silvery mackerel, grunnel, surfperch, etc. have never entered the main part of Lake Shinji-ko, although they distribute as far as the western part of River Ôhashi-gawa where chlorinity is about 10‰ in the bottom layer. Such a kind of discrimination of fish is also observable between the Sakai Channel and the northern part of Lake Naka-umi. Jack mackerel, Asian croaker, conger eel, Pacific sardine, etc. are the examples, that are absent in the latter area but are abundant in the former.

Many fishes, however, migrate between the three bodies of water from season to season, regardless of distinct differences in chlorinity between respective areas. It seems rather contradictory, if chlorinity alone is controlling distribution of fish, that many brackish fishes begin to enter Lake Shinji-ko in spring when chlorinity is at the minimum there. Similarly, most marine fishes are staying in Lake Naka-umi in warmer months, when the shallower layers of water than 3–5 metres have lower chlorinities. During these months bottom chlorinities are maintained at higher levels, especially in the southern part of the lake, a marked stratification of water appears, and the bottom water gives extremely low oxygen concentration, thus enabling no fishes to inhabit bottom layers. It is apparent that water temperature has controlling influences on the seasonal migration of fishes, as well as oxygen concentration decreasing therewith.

The winter water temperature in Lake Shinji-ko and winter surface water temperature in Lake Naka-umi drops down below 6°C, whereas the warmer water, higher than 10°C, is present on the bottom in the latter and Miho Bay. The distribution and seasonal migration of estuarine fishes, such as bay sardine, small silvery mackerel, halfbeak, etc., and marine fishes, such as striped mullet sea bass, anchovy, jack mackerel, etc. are occurring according to seasonal succession of water temperature of each region within the limits of salinity tolerance.

The differences are also noticed in distribution of fish within Lake Naka-umi. The fish fauna is comparatively simple in its southern part, namely both marine and weakly brackish fish are not represented there. The fact can not be explained in terms of differences in water temperature or chlorinity alone. In this case, perhaps, other factors as dissolved oxygen concentration should be taken into account.

Occurrence of the fish in particular areas is naturally regulated by biotic factors, especially food, and food and feeding behaviour of fish in the regions are discussed in relation to their migration in the next section.

Food of Main Fishes

Food and feeding habits of fishes are investigated mainly through the analysis of the gut contents, in which weighing the contents, counting numbers by food species and arranging them by points methods (SWINNERTON and WORTHINGTON, 1940; HYNES, 1950) were applied. Feeding habits of some fishes were observed directly in their natural habitats by skin diving or occasionally with the aid of the SCUBA. The results of examination of gut contents of major fishes are presented for each research region in Figs. 2, 3, 4, 5 and 6 to show food relationships.

In Lake Shinji-ko, each species of fish has its own restricted food habit and feeds practically on same food items throughout the year. Halfbeak, pond smelt, icefish and bay sardine feed on zooplankter. Benthic organisms are consumed by various fishes: shrimps and small invertebrates, such as chironomid larvae and oligochaetes, by crucian carp, small invertebrates by herbivorous chub, benthic invertebrates including corbiculan clams by carp, and bottom algae with detritus by striped mullet. Dace and sea bass feed on small fish and zooplankters, while common goby and freshwater eel feed on small fish and larger benthic invertebrates.

The food of herbivorous chub is noteworthy. It is known as an aquatic plant feeder both in Lake Biwa and in ponds in Nara Prefecture, to which its distribution had been originally restricted. (INANAMI, 1942; MAKI, 1964). It was introduced artificially to the lake a few years ago, and, because of the scarcity of aquatic plants here (SAKAMOTO, unpublished), it is supposed to have changed its food to feed on bottom invertebrates.

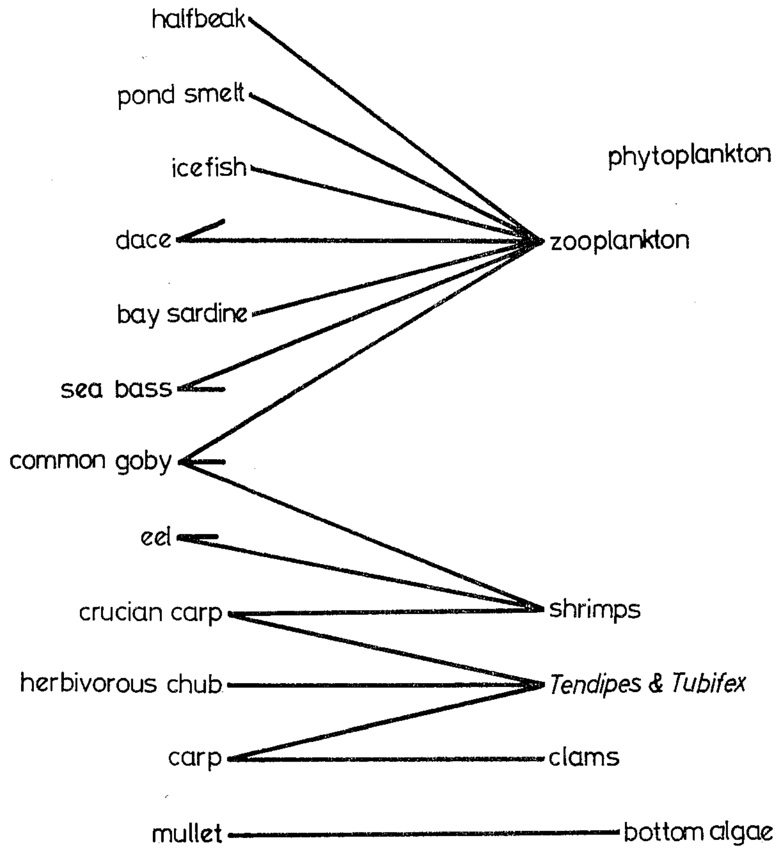

Fig. 2. Skeleton food-chain relationships between fishes and their food organisms in Lake Shinji-ko in summer and autumn.

Fishes inhabiting Lake Naka-umi feed on diverse organisms and change their food habits from season to season. For example, halfbeak feeds on zooplankters and sometimes on phytoplankters or epiphytes in the warmer season, while feeds on phytal amphipods and zooplankters in the colder season. Bay sardine takes zooplankters, especially copepods, in summer, phyto- and zooplankters in autumn and amphipods in spring. Small silvery mackerel feeds on zooplankters in summer, on phyto- and zooplankters, epiphytes, bottom algae as well as benthic molluscs in autumn, and on phytal amphipods in spring.

Common goby is principally piscivorous in the warmer season, but takes epiphytes, phytal animals, benthic molluscs, polychaetes and even zooplankters besides fish in the colder season. Striped mullet, on the contrary, feeds on bottom algae and detritus throughout the year.

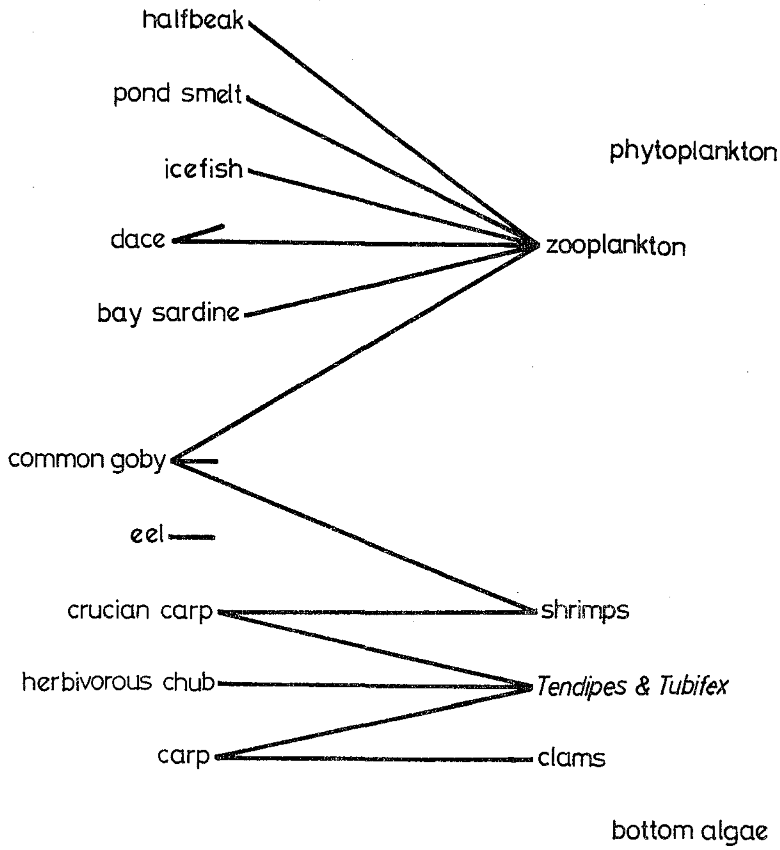

Fig. 3. Skeleton food-chain relationships between fishes and their food organisms in Lake Shinji-ko in winter and spring.

The summer food relations of fish in Lake Naka-umi are characterized a concentration of their foods to zooplankters, especially copepods as well as *Acetes* and *Neomysis* in less degree, being represented by halfbeak, bay sardine, northern anchovy, silverside, jack mackerel, small silvery mackerel, Asian pigfish and black rockfish. Piscivorous fishes such as sea bass, rockfishes, Asian croaker, freshwater eel, common goby and river flatfish are feeding on small fish in this season. If these feeding habits of fish are considered together with increased biomasses of a variety of phyto- and zooplankters, about two or four times more than in spring as shown in Table 1, and with abundance of fry and juvenile fish after spawning during spring and summer seasons, it will be noticed that these incidences are associated in time of occurrence.

Although the general trend in food relation of fish in summer is maintained,

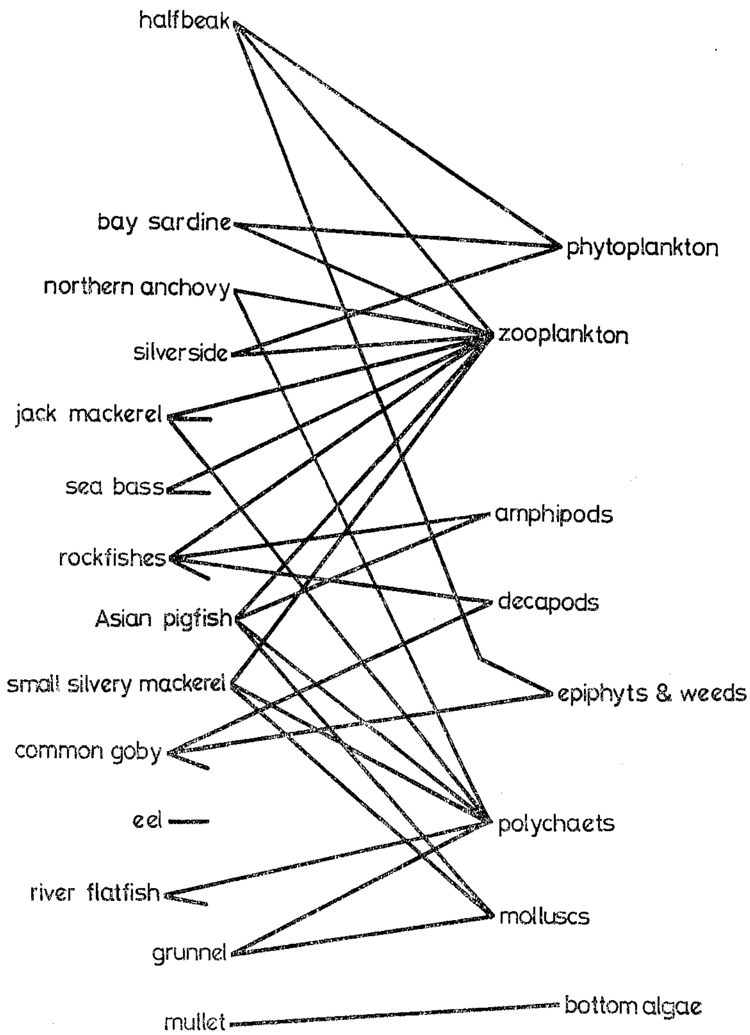

Fig. 4. Skeleton food-chain relationships between fishes and their food organisms in Lake Naka-umi in summer and autumn.

large weeds and polychaetes become important food items in autumn. Bay sardine, northern anchovy and silverside continue to feed mainly on phyto- and/or zooplankters, whereas small silvery mackerel forages on epiphytes, bottom algae, benthic molluscs and polychaetes as well, and Asian pigfish changes its foods mainly to molluscs and polychaetes. Halfbeak feeds also on large weeds besides plankters. Small fish are eaten still by piscivore group, such as sea bass, rockfishes, Asian croaker, freshwater eel, common goby and river flatfish, to which jack mackerel grown up by this season joins. At this time again,

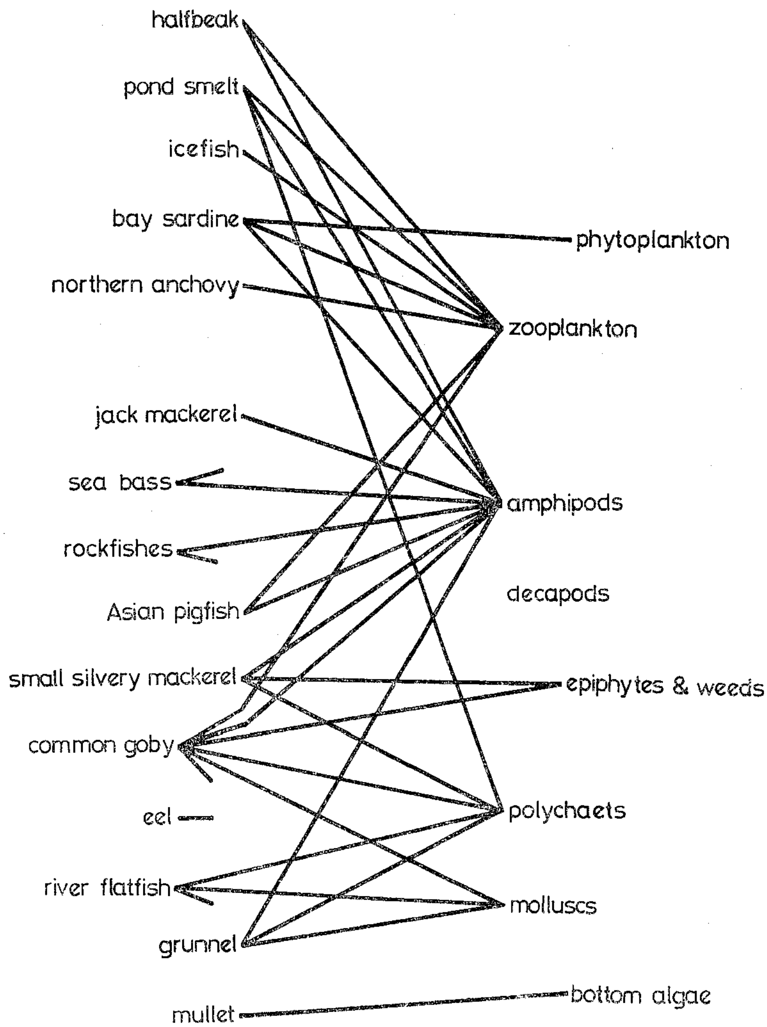

Fig. 5. Skeleton food-chain relationships between fishes and their food organisms in Lake Naka-umi in winter and spring.

the biomass of benthic invertebrates, almost all of which are depleted in summer, is increasing gradually up to four times more than in summer (Table 2; KIKUCHI, 1964). The time of increase in abundance of benthic invertebrates coincides with the time of fish to start to feed on them.

In winter, a majority of marine fishes migrate out from a the lake, and pond smelt and icefish enter the lake from Lake Shinji-ko instead. Halfbeak, bay sardine, pond smelt and icefish feed mainly on zooplankters and partly on phytal amphipods. Asian pigfish feeds on both zooplankters and phytal amphipods, whereas grunnel forages on amphipods and benthic invertebrates. Common goby is a sole piscivorous fish, but feeds also on zooplankters, phytal amphipods as well as benthic invertebrates.

In spring, when there is an overwhelming abundance of phytal amphipods, they comprise the most important portion of diet of almost all fishes living in

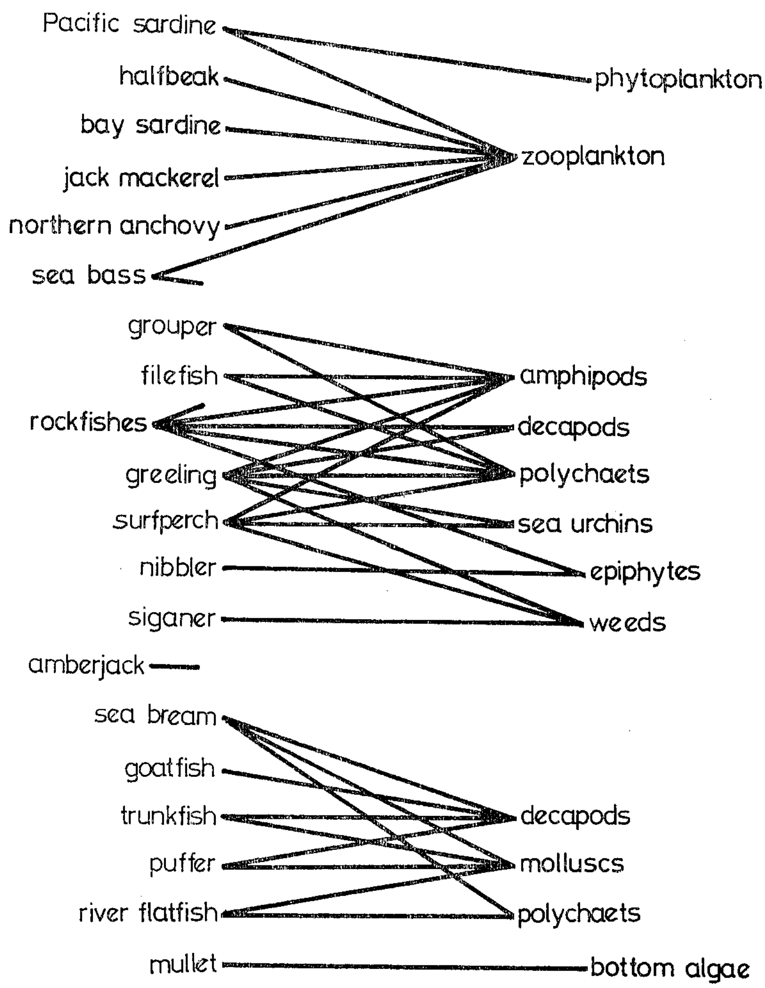

Fig. 6. Skeleton food-chain relationships between fishes and their food organisms in Miho Bay.

Lake Naka-umi, that characterizes the spring food relation of fish there. Halfbeak, pond smelt, bay sardine, jack mackerel, small silvery mackerel, Asian pigfish, rockfishes and grunnel feed mainly or entirely on amphipods; and icefish, sea bass and common goby feed partly on amphipods. The biomass of phytal animals in the lake in spring is about ten times larger than that in summer (KIKUCHI, unpublished ; HARADA, unpublished). Although the data on biomasses of phytal animals in autumn and winter are lacking, it is known that the biomass of phytal animals of which amphidods compose the major part increases during winter and reach to the maximum in spring (FUSE, 1962b ; KIKUCHI, 1966). So, it is not unnatural that many fishes feed mainly on phytal animals in this season. Northern anchovy, river flatfish and striped mullet, however, remain feeding on zooplankters, benthic invertebrates and bottom algae respectively. It should be pointed out here that zooplankters comprise no more than fifteen per cent of the total diet in typical plankton feeders such as halfbeak, pond smelt, bay sardine and jack mackerel.

Samples of fish from Miho Bay, examined for food analysis, include inhabitants of nearshore rocky areas and pelagic migratory fishes between Lake Naka-umi and Miho Bay. Halfbeak, bay sardine, jack mackerel, northern anchovy and Pacific sardine feed on zooplankters and/or phytoplankters ; while sea bass feeds on larger plankters and fish. Greelings, grouper, filefish and surfperch forage on shrimps, crabs, amphipods, polychaetes and sea urchins attached on large sea-weeds, and black rockfish on small fish as well, whereas nibbler and siganer graze on epiphytes or large sea-weeds. On the other hand, large crustaceans, molluscs and polychaetes serve as food for bottom feeding fishes like sea bream, goatfish, trunkfish, puffer, river flatfish, etc., and bottom algae and deiritus are consumed by striped mullet. It is generally known that reef fishes feed on various kinds of organisms, while other types of fish, especially pelagic, have relatively simple food habits, as suggested by many workers (e.g., SUYEHIRO, 1942). It is not surprising, therefore, that our results clearly demonstrate a wide variety of food items eaten by reef fishes, all of which are belonging to the category of phytal organisms. In other words, reef fishes in Miho Bay feed exclusively on phytal organisms, and do not feed on planktonic and/or benthic one.

Table 10 represents the food habits of fish in three bodies of water. It emphasizes changes of diet occurring in many fishes from area to area, that are also seen as seasonal variations. Halfbeak, pond smelt, icefish, bay sardine and jack mackerel, for instance, feed restrictedly on zooplankters throughout the year in Lake Shinji-ko and Miho Bay, while they feed not only on zooplankters but also on phytal and/or benthic organisms in Lake Naka-umi. In the same way, phytal animals form the principal food items of black and yellow rockfishes and benthic invertabrates constitute a sole food source for river flatfish in Miho Bay, whereas these fishes feed on zooplankters, phytal animals and/or benthic invertebrates in Lake Naka-umi. It is particularlly interesting that in Lake Naka-umi food habits of a majority of fish are varied seasonally, namely from phytal animal feeding to zooplankton feeding, then to benthos

Table 10. Comparison of main food items of fishes, as these fishes are inhabiting Lake Shinji-ko (S), Lake Naka-umi (N) or Miho Bay (M).

grouped food items / fish species	phytoplankters	plankton crustaceans	*Neomysis* & *Acetes*	large weeds, etc.	epiphytes	phytal crustaceans	phytal molluscs	level bottom algae	shrimps and crabs	molluscs	oligochaetes	polychaetes	fish egg or fries	free-swimming fish	benthic fish
pond smelt	—	SNM	SN	—	—	N	—	—	—	—	—	N	—	—	—
icefish	—	SN	—	—	—	N	—	—	—	—	—	—	—	—	—
halfbeak	—	SNM	—	—	—	N	—	—	—	—	—	N	N	—	—
northern anchovy	—	NM	—	—	—	—	—	—	—	—	—	N	—	—	—
bay sardine	N	SNM	SNM	—	—	N	—	—	—	—	—	—	N	—	—
shad	—	SNM	SNM	—	—	N	—	—	—	—	—	—	—	—	—
silverside	N	NM	NM	—	—	—	—	—	—	—	—	—	—	—	—
Pacific sardine	NM	NM	—	—	—	—	—	—	—	—	—	—	—	—	—
jack mackerel	—	NM	NM	—	—	N	—	—	—	—	—	N	NM	NM	—
flying fish	—	NM	NM	—	—	—	—	—	—	—	—	—	NM	NM	—
sea bass	—	—	SN	—	—	NM	—	—	—	—	—	N	SNM	SNM	—
black rockfish	—	—	—	—	—	NM	NM	—	—	—	—	—	—	NM	—
yellow rockfish	—	NM	—	—	—	NM	NM	—	—	—	—	—	—	NM	—
small silvery mackerel	—	N	—	—	NM	NM	NM	N	—	—	—	N	—	—	—
Asian pigfish	—	NM	—	—	—	NM	—	—	—	—	—	NM	—	—	—
nibbler	—	—	—	NM	NM	NM	—	—	—	—	—	N	—	—	—
surfperch	—	N	—	NM	NM	NM	—	—	—	—	—	N	—	—	—
greelings	—	—	—	NM	—	NM	NM	—	N	N	—	N	—	—	—
freshwater eel	—	—	—	—	—	—	—	—	N	N	—	N	—	SN	SN
striped mullet	—	—	—	—	—	—	—	SNM	—	—	—	—	—	—	—
crucian carp	—	—	—	—	—	—	—	S	S	—	S	—	—	—	—
carp	—	—	—	—	—	—	—	—	—	S	S	—	—	—	—
common goby	—	N	N	N	—	N	—	—	SN	N	—	N	—	SN	SN
Asian croaker	—	N	—	—	—	N	—	—	—	—	—	NM	—	N	NM
river flatfish	—	—	—	—	—	—	—	—	—	NM	—	NM	—	N	NM
grunnel	—	—	—	—	—	N	N	—	—	N	—	NM	—	—	—
dragonet	—	—	—	—	—	N	N	—	—	NM	—	NM	—	—	—
sea bream	—	—	—	—	—	N	—	—	M	NM	—	NM	—	—	—

feeding, and again to phytal animal feeding. All this evidence in combination with the fluctuations of biomass of such food species living in the lake may indicate that fish feed always on the organisms which are most numerous in each season (Steven, 1930).

On the Signifficance of Euryphagous Habit for Fish Production in Estuarine Water

It is a well known phenomenon that a relatively wide range of fish and invertebrates is characteristic to estuarine brackish water which is accordingly established in many cases as a good fishing ground. As contributing to the creation of conditions leading to such variety and high amount of brackish biota, several favouring factors have been recognized and suggested (e.g. KORRINGA, 1964; HEDGPETH, 1966). We may add the significance of the broad food preference of fish in increasing fish production in estuarine brackish environment.

As was mentioned in the preceding section, fishes living in Miho Bay have their own restricted food habits. Such a phenomenon has been recognized by many workers. For example, HIATT and STRASBURG (1960) distinguished coral reef fishes into fifteen categories from their food and feeding habits. The fourteen categories of these were all of restricted food habit and the rest one, omnivorous as these authors named, includes only two species feeding on plankton animals and benthic organisms and the remainder foraging indiscriminately on both animals and algae attached on coral reef. OKUNO (1956) and FUSE (1962b) also noticed that each species of rocky reef fishes fed on a definite type of organisms such as pelagial, phytal or benthic. In shorter words, marine fishes can be denoted to have restricted food and feeding habits. In the case of reef fishes, which are usually recognized as omnivorous feeders, if food species of each of them are looked ecologically, it is evidently indicated that these food species belong to a particular category of life, that is, the food is restricted within a definite ecological type of organisms. It seems to be exceptional in marine fishes that a particular stage of a fish feeds simultaneously on organisms of varying ecological types, that is to say, planktonic, benthic or phytal organisms.

Freshwater fishes have been considered, on the other hand, that they have in general very broad food preferences. In rivers, HARTLEY (1948), KAWANABE (1959), MIYADI, KAWANABE et al. (1961), for instance, described that most fish ate all kinds of planktonic, benthic and nektonic organisms and discussed the effect of the composition and standing stock of food organisms and of the social organization of fish themselves upon the change of fish diet. In an impoundment it was observed that most fish feed on zooplankters in warm season but on benthic animals in cold season (MIURA, 1959). However, in natural lakes, it is widely believed that a particular stage of a particular species of fish has its own preferred food items and type of feeding, and incidentally that the fishes can be assigned to several types from their foods and feeding habits (e.g. INANAMI, 1942). In the present case of fish of Lake Shinji-ko, each species is similarly restricted to certain food items throughout the year, as is shown in the preceeding section. So, it may be concluded that freshwater fishes have naturally their own preferable food items, while, at the same time, they are ascribed to with the ability to change their diet and habitat under varying circumstance. Where environmental conditions are stable and mild, fishes persist on preferred foods and feeding habits; while fishes may change diet and feeding habit from their original states where environmental conditions are vagile or unfavourable.

On the contrary, in Lake Naka-umi, most fishes change their food habits seasonally and even within a season they are actually feeding on broad categories of food organisms. Such a phenomenon was observed also in a *Zostera* belt by FUSE (1962a). DARNELL (1958, 1961) intensively studied on the food habits of fishes and large invertebrates in an estuarine lake and described that a group of particular size of a particular species of fish often consumed significant amounts of material from several different sources. For example, bay anchovy (*Anchoa mitchilli*) ate fishes, zooplankters, bottom animals and detritus, and Atlantic croaker (*Micropogon undulatus*) ate zooplankters, bottom animals and detritus. In his presentation of data, however, DARNELL did not refer to seasonal changes in food habit, and it is not clear whether the fishes were changing their food habits seasonally or they were taking different categories of food items at a time.

From the foregoing arguments it would be inferred that estuarine fishes, comparing with freshwater and marine fishes, change greatly their diets according to season. Moreover, it may be pointed out from the present investigation that a particular fish holds narrower food habit in freshwater and marine environments, while it shows broad food preference when it comes into the brackish or estuarine water. Lake Naka-umi in the present case, or estuarine water in general, although very fertile, is a remarkably unstable habitat. Most organisms inhabiting there, especially lower animals, being influenced much by changing environmental conditions, are not maintaining a definite level of population throughout the year, but, given a favourable condition, explosive population increase may occur in them. Thus, such a mode of life of fish as changing food items in varying circumstance seems to be very well adapted to such features of remarkably unstable environment.

For such euryphagous fishes, food condition may be much better in Lake Naka-umi than in Miho Bay, at least in the warmer season. Biomass of zooplankters are similar between the two bodies of water in spring or autumn, but it is much larger in Lake Naka-umi than in Miho Bay in summer. Biomass of phytal animals estimated from the collection by large cone-net is about 3.3 g-dry weight/m^2 in the former, while it is about 0.92 g-dry weight/m^2 in the latter in spring (HARADA, unpublished). The migration of many euryphagous marine fishes into Lake Naka-umi during the warmer season may partly be attributable to such a huge biomass of food organisms.

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